ECONOMIC IMPLICATIONS OF EMISSION UNCERTAINTIES: THE CASE OF BIOSPHERIC METHANE EMISSIONS FROM RICE CULTIVATION

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ABSRACT

Methane (CH_4) and nitrous oxide (N_2O) are the second and the third most important greenhouse gases, respectively, and neglecting them would most likely result in sub-optimal policies. However, the uncertainties in non-CO2 greenhouse gas emissions are often significant, specifically biospheric emissions, and important questions arises as to how these uncertainties should be handled in a cap and trade system, like the permit trading system set up in the Kyoto Protocol. Depending on how the uncertainties are managed, it can have large economic implications. In this paper, we study how a trading program could work, in particular we estimate the cost of meeting a specific emission abatement target for various degrees of certainty that the target is met. Our results indicate that the policy used for uncertainties has a significant impact on permit prices as well total global cost of meeting our assumed commitments. When illustrating the impact of uncertainty, we choose to focus on methane emissions from rice fields in China. Our results suggest that the costs for China to meet its GHG target increases by 2-35 % if methane emissions from rice fields are included in the national emissions budget, but efforts to reduce methane emissions from rice fields are neglected.

1.0 INTRODUCTION

Several recently published research articles has highlighted the economic gains of including the non CO_2 greenhouse gases in strategies reaching the Kyoto target (Reilly et al, 2002) as well as long-term targets(Tol et al, 2003) and (Reilly et al, 1999). However, these articles have not discussed how to approach the large uncertainties in the scientific knowledge as well as biases in global, regional and national budgets in many of these emissions. Two main problems arise because of the uncertainties. First, real progress towards lower emissions of greenhouses gases might get lost if abatement is primarily focused on emissions which are overvalued (the actual emissions are lower than the estimated quantity so that the actual reductions are overstated). Second, in a permit market where emissions and abatement cannot be satisfactorily monitored and verified (or when monitoring and verification are very costly), the sellers of permits can strategically over- or underreport emissions and abatement results. Some analysts have even warned that the large problems with monitoring and verification might wreck the whole Kyoto process (Victor, 2001).

In this paper, we present an economic model of the cost to meet various greenhouse gas abatement targets. The key aim of the model is to analyze the impact of different approaches to uncertainty – both in the actual emissions and the effect of abatement strategies. Other papers that have analyzed and discussed uncertainty and greenhouse gas abatement strategies include Godal et al (2003) and Tietenberg (2003).

Three key questions are addressed:

- How is the cost to meet a stringent greenhouse gas abatement target in the year 2020 affected by different requirements on how certain we want to be that we actually meet the target?
- In which direction does uncertainties about emissions and abatement rates affect the optimal tax? Should it be lower or higher? (Alternatively, if a cap and trade approach rather than a tax approach is taken; how many permits should uncertain reductions generate?)
- Methane emissions from rice fields make up a significant share of China's greenhouse gas emissions. How much more costly would it be for China to reach a specified multi-gas target if abatement rice related methane emissions were excluded in a cap and trade system the year 2020?

2.0 THE MODEL

For the purpose of this paper, we have developed a non-linear optimization model to estimate the cost of greenhouse gas abatement targets. It is a two-region model (China and the Rest of the World (ROW)) and we have chosen to include CO_2 from fossil fuel use and all anthropogenic CH_4 and N_2O emissions in the two regions. For China we have chosen to separate CH_4 emissions from rice cultivation from other CH_4 emissions. The model seeks to minimize the costs of meeting any specific target (either combined greenhouse gas targets, or targets for each specific gas).

Abatement options are modeled through the use of marginal abatement costs curves (MAC). The CO_2 cost abatement curves are taken from (Ellermann et al, 1998) and the CH_4 & N_2O curves, except that describing the cost of methane abatement from rice fields in China, are from Reilly et al (2002). We have developed a cost curve for methane abatement from rice fields based on data in Kern et al (1997), Verburg et al (2001), ALGAS (1998) and Denier Van Der Gon et al (2001). The estimation procedure can be obtained from the authors upon request.

Further, each region has to meet a per capita constraint by either reducing its own emissions or purchasing emissions allowances from the other region. The baseline scenarios are from IS92a (IPCC, 1992) and the ALGAS study (1998). We then assume that each country has equal per capita emission permits. One may doubt the political feasibility of a per capita allocation already by the year 2020, but we have chosen this for the sake of illustration. The per capita constraint is estimated from the model described in Persson et al 2003 and is based upon an emissions trajectory meeting a temperature target of 2 ^{o} by the year 2100. We find that the global average CO_2-equivalent emissions in the year 2020 to be 1.37 ton/capita/year

2.1 HOW TO DEAL WITH UNCERTAINTIES

The response from the scientific world on how to deal with the uncertainties in greenhouse gas emissions and abatement results has been fairly slow. In this paper we present a formal mathematical model to deal with uncertainties based on chance constrained programming. We assume that each partner involved in the trading scheme has to meet its individual commitment to a predetermined degree of certainty. Further, we assume that there is uncertainty about both the emissions and the effect of abatement policies.

The overall aim of cost effectiveness can be stated as the following optimization problem

$$Min \sum_i \sum_g TC_{ig}$$

$$s.t.$$

$$P\{Q_i \leq Q_i^* + IM_i - EX\} \geq \Phi$$

$$\sum_i IM_i = \sum_i EX_i$$

where P is the probability, TC_{ic} is each regions total abatement cost for each gas, IM_i and EX_i the import and export of permits and F the degree of certainty that each region/nation meets its emission target, Q_i^*. Sellers are assumed being liable in the allowance trading system and they have to meet their emission target to a certain degree of predetermined certainty (the probability has to be larger than Φ) and can sell additional reductions. These permits are then traded as if they were 100 % certain.

The probabilistic constraint can be converted to a deterministic equivalent, which can be written as

$$E(Q_i) + K_\Phi \sqrt{Var(Q_i)} \leq Q_i^* + IM_i - EX$$

where K_F is the number of standard deviation that has to be accounted for when meeting the requested degree of certainty, F, $E(Q)$ is the expected value of the emissions and $var(Q_i)$ is the variance of the emissions.

We assume that all probability density functions for emissions and abatement are normally distributed. The assumption of normally distributed variables is indeed a rough assumption, but the lack of data might excuse this approach. Qualitatively aspects of the results are likely to be invariant to the choice of distribution. Further, it is assumed that the emissions of the different gases are independent.

Where $i=1, \ldots,m$ represent regions and $g=1,\ldots,n$ different greenhouse gases. Let q_{ig} be the expected emissions of each gas in each region and let e_{ig} represent the uncertainties in the emission estimates, further let a_{ig} be the expected percentage reduction and f_{ig} the uncertainties in abatement. Then the emissions from each region would be

$$Q_i = \sum_g q_{ig}(1+e_{ig})(1-a_{ig}(1+f_{ig}))$$

The expected emissions from each region are then

$$E(Q_i) = E\{\sum_g q_{ig}(1+e_{ig})(1-a_{ig}(1+f_{ig}))\} = \sum_g q_{ig}(1-a_{ig}).$$

the variance of the total emissions can be expressed as

$$Var(Q_i) = Var\{\sum_g q_{ig} - q_{ig}a_{ig} + (q_{ig} - q_{ig}a_{ig})e_{ig} - q_{ig}f_{ig}a_{ig} - q_{ig}e_{ig}f_{ig}a_{ig}\} =$$

$$\sum_g (q_{ig} - q_{ig}a_{ig})^2 Var(e_{ig}) + \sum_g q_{iq}^2 a_{ig}^2 Var(f_{ig}) + \sum_g q_{iq}^2 a_{ig}^2 Var(e_{ig}f_{ig})$$

Using the error propagation equation, or the Gaussian approximation formula, we may rewrite last the term as

$$Var(e_{ig}f_{ig}) \approx Var(e_{ig}) + Var(f_{ig})$$

2.2 ESTIMATES OF UNCERTAINTIES

The uncertainty estimates are rather crude. However, since the focal point of this paper is on the existence of uncertainties and their qualitative implications, the crudeness of the used figures should be acceptable. Based on data in (Rypdal & Winiwarter, 2001), (Gawin, 2002), (EIA, 1999) and IPCC(2000), we neglect the uncertainties in CO_2 emissions from fossil fuels, the standard deviation in the reviewed studies are in general less than a few percent, for CH_4 emissions we estimate that the standard deviation is 20 % of the emissions, for N_2O 60 % of the emissions and for CH_4 from rice in China we estimate the standard deviation to 35 % of the emissions, see below. We assume the same relative uncertainties for abatement results as for the uncertainties in the emissions.

2.3 METHANE EMISSIONS FROM RICE FIELDS

CH_4 emissions from rice fields are a result of anaerobic decomposition of organic materials and are estimated to contribute to about 5- 25 % of the global methane emissions. Measurement campaigns have estimated the CH_4 emissions from irrigated fields to vary between 20-600 kg CH_4 per ha per season. Also within a single hectare the emissions can vary considerably. As a result, estimated emissions from rice fields as well as the effect of abatement measures are uncertain and difficult to monitor and verify.

To get a rough overview of uncertainties in the estimates of the methane budget from rice cultivation in China we assessed all articles we could find published later than 1990, see Figure 1. We estimate the mean value of these studies to be 12.26 Tg/year and the standard deviation to be 4.26 Tg/year.

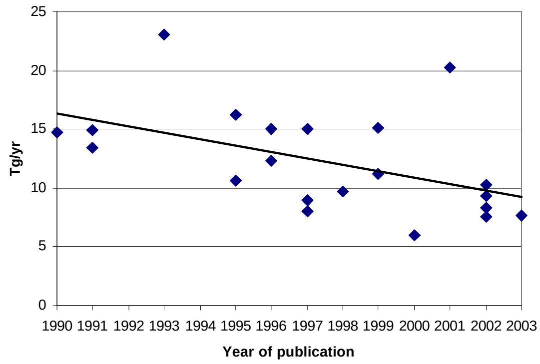

Figure 1: Estimates of methane emissions from rice field sin China reported in international scientific journals after 1990 (Sources to this graph can be obtained from the authors of this paper upon request).

The linear trend of the estimates shows a decline in the estimated budget for rice related methane emissions in China, although the trend is not accounted for in this study.

3.0 RESULTS

Our main findings are that both the marginal cost and global total cost increases substantially with increasing requirements on the certainty that the emission reduction target is met. This is seen in Figure 2a, where the global cost of meeting our per capita target is shown as a function of the certainty that the target is actually met, the higher certainty we require, the more CO2 abatement takes place in lieu of the more uncertain reductions in methane.

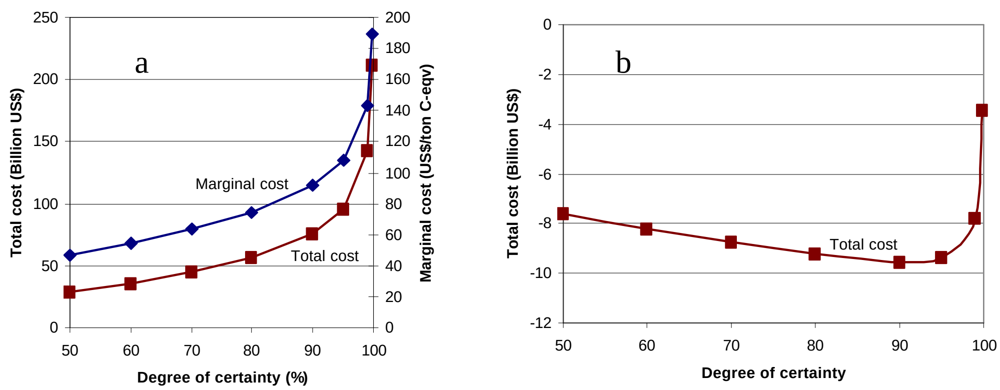

Figure 2: Figure a shows the global total cost and the marginal abatement cost (permit price) of meeting the specified target, while figure b shows the cost for China meeting its specified target.

For China (see figure 2b), the total cost is negative, i.e. China will benefit from the assumed greenhouse gas target as a result of net export of emission permits. This income increases with the increasing conservativeness towards uncertainties, as a result of increased permit prices. However, when targets have to be met with a degree of certainty above 90 %, the income starts to fall as a result of increasing national costs.

Also, as the uncertainties in the N_2O and CH_4 emissions are larger than for emissions of CO_2, the relative importance of abatement of the uncertain emissions depends on if the uncertainties are in baseline emissions or abatement results, see table 1. In the special case when there are no uncertainties in abatement, but in baseline emissions, the optimal tax on the expected emissions should be higher than for absolutely certain emissions. In a cap and trade system one expected reduction in these uncertain baseline emissions should generate additional permits than if the emissions would have been certain. In the opposite case, were pre-abated emissions are perfectly known, but the abatement result is uncertain, the optimal tax on expected emissions should be lower than for absolutely certain emissions. In a cap and trade system one expected reduction in these emissions should generate fewer permits than if the abatement would have been certain.

Table 1.The table shows how the optimal tax should be if baseline emissions or abatement rates are uncertain, in relation to the optimal tax on certain emissions.

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="2">Abatement</th></tr>
<tr><th>Certain</th><th>Uncertain</th></tr>
<tr><td rowspan="2">Emissions</td><td>Certain</td><td>No change</td><td>Lower</td></tr>
<tr><td>Uncertain</td><td>Higher</td><td>In general lower</td></tr>
</table>

The costs for China to meet its GHG target if methane emissions from rice fields are included in the national emissions budget, but efforts to reduce GHG emissions from rice fields are neglected are estimated in figure 3. The reason for neglecting abatement of CH_4 emissions fro rice fields can stem from various reasons, e.g. wrongly designed policy measures can have consequences for small scale farmers' ability to generate income and the food security in the region. The loss increases with increasing uncertainty in emissions and increasing conservativeness. This is simple to interpret, since increasing conservativeness values uncertain emissions higher, so, increasing both conservativeness and the uncertainty results in an increasing loss of not abating these emissions. Further, increasing conservativeness implies higher permit prices. The loss in monetary terms of neglecting rice related methane is in the order of US$ 200 million up to US$ 3 billion in the year.

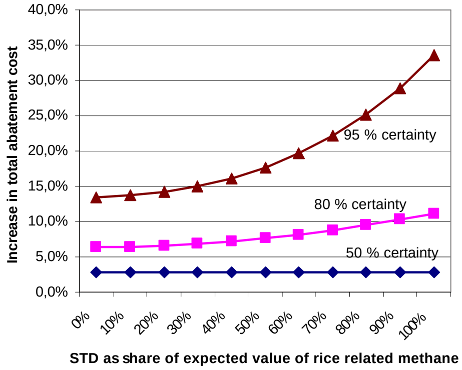

Figure 3: The relative loss of income generated by the emission permit program if abatement of rice related methane is excluded in abatement strategies.

4.0 DISCUSSION

Both the global total cost and the marginal cost increases with increasing degree of conservativeness towards uncertainties. However, one has to estimate benefits of higher certainty that targets are met to the extra costs of the conservativeness. On the one hand the opportunities for strategic behavior decreases, real emissions reductions are undertaken and efforts to reduce uncertainties in national greenhouse gas accounts are likely to be implemented. On the other hand increasing the short-term cost of abatement can be a waste of limited capital and complicate the process towards more stringent emission targets. Further, our model is static, while the problem with climatic change and its abatement policies are long-term. Approaching the problem with uncertainties in emission and abatement strategies using static methods has its limitations. The uncertainty in emissions and emissions reductions are expected to decline over time. Continuous observations of the atmospheric concentrations of the relevant greenhouse gases and increasing knowledge about emissions inventories are likely to decrease uncertainties in baseline emissions and abatement strategies. If claimed emission reductions later turn out to be overestimated, this can be compensated by implying harder targets later on or by implementing a system with long-term liability of compliance with past emission targets. These methods can compensate for a less strict approach towards uncertainties earlier on. A dynamic model that takes into account the effects of learning and observations of actual atmospheric concentration is under development by the authors.

Excluding methane emissions from rice fields in a cap and trade system could significantly decrease the income generated by the net export of emission permits from China. Our results indicate that the potential loss of excluding abatement of rice related methane is in the order of 2.5 % up to almost 35 % of the income generated by the emission permit program. In monetary terms, the negligence of abating rice related methane implies a loss of income in the order of US$ 200 million up to almost US$ 3 billion.

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